(53% VS 63%) US-183, ROOKS COUNTY, KANSAS

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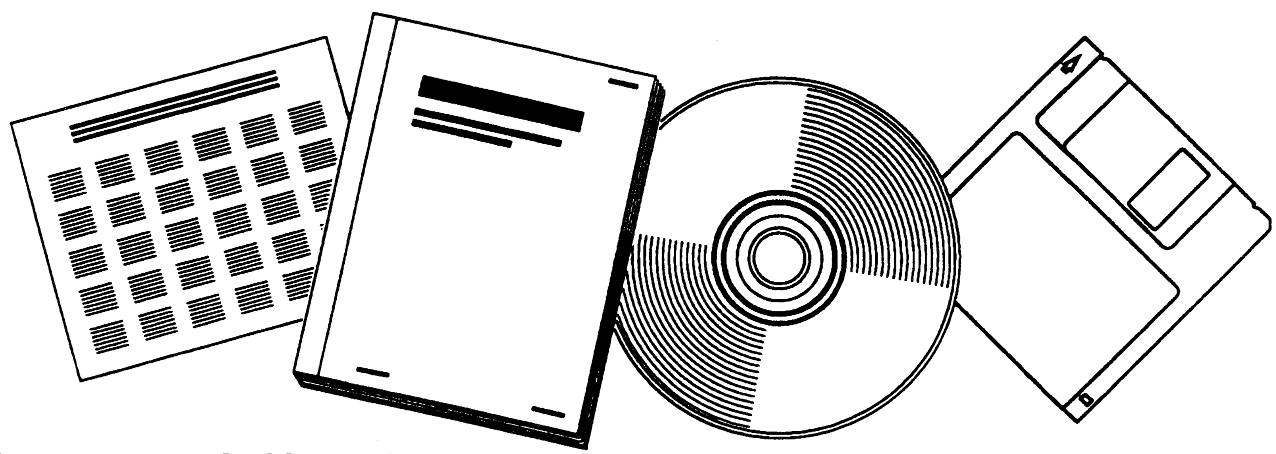

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Final Report

PERFORMANCE OF BITUMINOUS MIXES WITH VARYING PERCENTAGES OF CRUSHED AGGREGATES (53% vs. 63%) US-183, ROOKS COUNTY, KANSAS

Glenn A. Fager

May, 1997

KANSAS DEPARTMENT OF TRANSPORTATION

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16. Abstract

In 1980 a construction project was constructed with two different bituminous mixes that incorporated 53% and 63% crushed aggregates. The project was designed using the 50-Blow Marshall method. The pavement was unstable because it rutted during the 11 years that it was monitored. Cracking was low when compared to the original roadway. Rut depths varied in which the pavement with the 63% crushed aggregate rutted 16% less than the pavement with the 53% crushed aggregate. The additional 10% crushed aggregate (63% vs. 53%) resulted is a 3.8% increase in cost.

The report also includes a laboratory study of "Crushed vs. Uncrushed Aggregates in Bituminous Mixes". The report concluded that increasing the crushed aggregate above 50% will result in increased mix stiffness.

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INTRODUCTION

Rutting or permanent deformation has been one of the major concerns of highway engineers for many years. All asphalt pavements in the United States have experienced premature failure due to rutting. Truck tire pressures are in the range of 70 to 80 psi, and future truck tire pressures have been estimated to be more than 100 psi. Total gross weights and volume of traffic has increased as well, and probably will continue to increase. Since higher tire pressures, increased loads, and volume of traffic appear to be inevitable, it is necessary for materials engineers to consider the asphalt concrete mixture and its components in order to formulate a rut resistant asphalt mixture.

Many researchers have shown that crushed aggregate increase the stability (resistance to deformation and plastic flow) of hot mix asphalt concrete. Recent studies have shown that crushed aggregates, through interlocking and shear resistance, can improve the mix strength and resist rutting and shoving.

A laboratory study in 1989 concluded that increases in the crushed limestone aggregate above 50%, will result in increased creep modulus stiffness. A copy of this report is listed in the Appendix.

In December 1978 the surfacing committee and District 3 decided to construct a 3.5" bituminous mix (BM-2) with two different crushed aggregate percentages. One half of the project would be built using 50% crushed material, and the other half using 60% crushed material. The location of the project was on US-183 in Rooks County as indicated in Figure 1. The project was "let" under normal bid procedures and actual cost data is available later in this report. A 500' control section using 50% crushed aggregate would be compared and monitored against a 60% crushed aggregate 500' test section.

CONSTRUCTION

The project was designed for two different mixes (50% and 60% crushed aggregates). However, at construction time, records indicated that the actual mix incorporated 53% and 63% crushed aggregates in the 50-Blow Marshall mix design. The crushed aggregate differential of 10% was maintained between the two mixes. The gradations of the two mixes are presented in Table 1. The 3.5" BM-2 overlay was built in 1980. Two 500' control and test sections were setup for monitoring as indicated in Figure 2. A preconstruction crack survey of the road had been completed prior to the overlay. Any cracking that occurred after the overlay, would be referenced as a percentage of the amount of cracks that existed prior to the overlay.

POST CONSTRUCTION EVALUATION

The control and test sections were monitored for rutting and cracking from the time of construction to 1991. At that time, a slurry seal was constructed over the overlay which terminated all future crack surveys and rut measurements. Both crack and rut data is presented in Table 2 and 3. As can be seen from the data, the additional 10% increase in crushed rock seems to help reduce the amount of rutting. The control section rutted an average of 0.63" after 11 years of traffic. The test section (with additional rock) rutted 0.53" or 16% less than the control section.

The cause of the rutting was not investigated, therefore not determined. However, it was noted that the air voids in the Marshall designs were 2.5 and 3.0% at the recommended asphalt content. It is quite possible that the low design voids caused both mixes to become unstable.

The amount of cracking after 11 years in both sections is low when compared to the original roadway. This is probably due to the pavement becoming slightly unstable and moving or flowing during the summer months. The cracks would tend to heal themselves during the hot weather.

COST DATA

The cost of the two mixes was based on bid prices derived from a normal bidding process. The quantities of the aggregates were substantially high enough (8000 tons) to justify a reasonable comparison of the cost of both mixes. The bid and mix prices are presented in Table 4. The asphalt content of both mixes was the same (5.25%) so the mix price increase was a direct result of the increased aggregate cost.

CONCLUSION

The additional 10% crushed aggregate resulted in a 3.8% increase in cost. However, the 3.8% increase in cost probably resulted in a 16% reduction in rut depths. Therefore, it appears that the added cost of increasing the crushed aggregate from 53% to 63% results in decreased rut depths.

TABLE 1 MIX GRADATIONS

Aggregate Type		PERCENT RETAINED-SQUARE MESH SIEVES									
		3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
		53% Crushed Aggregate / Sieve Analysis / Square Mesh / Percent / Retained									
CS-1	30	0	30	69	94	96	97	97	97	98	99
CS-2	23	0	0	0	3	27	40	49	62	82	88
SSG-1	41	0	0	2	9	30	58	80	93	96	96
MFS-5	6	0	0	0	0	1	2	6	11	16	26
	0	0	0	0	0	0	0	0	0	0	0
	100	0	9	21.52	32.58	47.37	62.2	73.53	82.15	88.58	90.86
		63% Crushed Aggregate / Sieve Analysis / Square Mesh / Percent / Retained									
CS-1	31	0	30	69	94	96	97	97	97	98	99
CS-2	32	0	0	0	3	27	40	49	62	82	88
SSG-1	31	0	0	2	9	30	58	80	93	96	96
MFS-5	6	0	0	0	0	1	2	6	11	16	26
	0	0	0	0	0	0	0	0	0	0	0
	100	0	9.3	22.01	32.89	47.76	60.97	70.91	79.4	87.34	90.17

TABLE 2. Crack Survey (% of total original cracking)

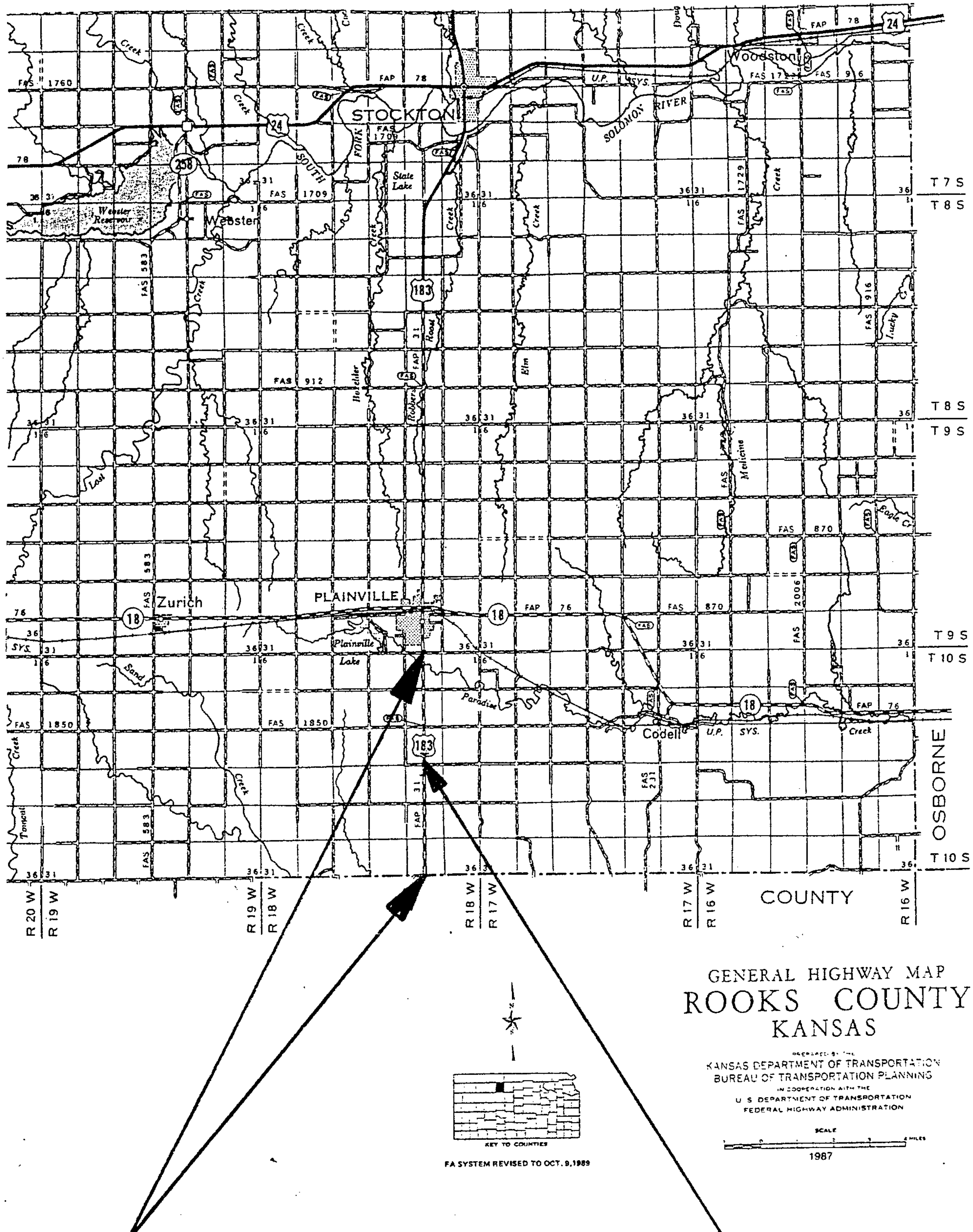
Date	50% Crushed Aggregate	60% Crushed Aggregate
06-01-1980	(Construction)	
04-13-1984	0	0
10-09-1984	0	0
04-08-1985	0	0
10-01-1985	0	0
04-07-1986	0.7	0
10-13-1986	1.7	0
10-06-1987	1.9	0
04-21-1989	3.0	0
10-24-1989	4.3	0
04-29-1991	13.8	3.2

TABLE 3. Rutting Survey (in.)

Date	50% Crushed Aggregate (in.)	60% Crushed Aggregate (in.)
06-01-1980	(Construction)	
07-28-1987	0.52	0.40
10-06-1987		0.44
10-24-1989	0.75	0.625
07-23-1990	0.61	0.50
05-01-1991	0.63	0.53

TABLE 4. Cost Data

	50 % Crushed Aggregate ($/Ton)	60 % Crushed Aggregate ($/Ton)
Aggregate	14.50	15.25
Asphalt	107.00	107.00
Mix	19.11	19.83 (3.8% Increase)



Project Location

Control and Test Sections

Figure 1. Project and Test Sections

KANSAS DEPARTMENT OF TRANSPORTATION

Bureau of Materials and Research

Research Unit

CRUSHED VS. UNCRUSHED AGGREGATES IN BITUMINOUS MIXES

by

Glenn A. Fager, P. E.

October 1989

INTRODUCTION

There has almost always been an universal opinion that adding crushed aggregate to bituminous mixes will inhibit or slow down the amount of highway wheel path rutting. I think most highway engineers will agree that adding crushed particles will "help" our mixes. The only exceptions may come from our chat aggregates where "stripping" may be a problem or in the 100% crushed stone mixes where "harshness" may present some workability problems.

The purpose of this laboratory study was to measure the differences among the mixes and to see how those mixes are affected by the addition of crushed particles. The Marshall Test Method (ASTM D 1559) and Gyratory Test Machine (GTM) Method (ASTM D 3387) were used to make the comparisons.

MATERIALS

Before any design and laboratory test can be accomplished, an aggregate source, gradation, and asphalt supply need to be established. Checking the current Marshall mix designs showed a typical bituminous surface mix was a BM-2 with a VAC-10 asphalt cement. A typical gradation target is shown on the top of Table 1 and Figure 1. Table 1 also shows the three different mixes. Crushed limestone (CS) from Linn County was used for the angular aggregate and sand from the Kansas River was used for the uncrushed or nonangular material. All of the final combined gradations, on each sieve size, were controlled to within 1%. The gradation of the sand (SSG) was held constant. Only the amount of the SSG varied. The total combined gradation was maintained to within 1% so the only variations would be in the crushed stone content and their percentages. In other words, the gradation of the CS and the percentages of both the CS and SSG were the only material variations.

The next step was to determine an appropriate asphalt content to be used with all three mixes. To determine the AC content, the mix was "designed" by the Marshall method. Both of these methods (Marshall or Gyratory) can be used to pick an asphalt content and evaluate the mix as well.

DESIGN

The asphalt content (A/C) was varied and gyrographs produced from the GTM. The same A/C contents were used on each mix. A summary of the data is presented in Table 2. Forty-five(45) revolutions were used as the design point on each graph. From these graphs, an A/C content of 5.25% was selected to compare each mix for the Marshall check and creep stiffness measurements. Densities were measured in three different ways according to the KDOT Construction Manual (KT-15), Procedure I, III, & IV. Procedure I (weight in air/weight in water) is the more traditional method. Procedure III is similar to the Asphalt Institute recommended method. Procedure IV is probably more close to the actual material density.

RESULTS

Creep Stiffness measurements were conducted using the Shell method or the Static Creep method. All creep tests were conducted at 104 degrees F (40 C) for at least 60 minutes. Loading had to vary depending upon the "softness" of the mix. Bituminous cylinders for the tests (4" dia. x 7" length) were molded on the kneading compactor at various densities.

The Creep Stiffness Modulus will increase as densities of the mixes increase. The problem with a standard density value is that this would not be realistic with certain "open" mixes if compared with more of the "closed" mix designs. Therefore, the question is what standard density should be used?

A more realistic comparison of the Creep Stiffness Modulus would be at the same compactive effort. KDOT specifications require a road density on surface courses to be at least 96% of the field molded density. In most cases, the field molded density is the density produced from 50 blows from a Marshall hammer. If the mix was road compacted to at least 96% Marshall density, it is reasonable to expect the road density to attain 100% after a few years. Therefore, for this study, the Creep Stiffness Modulus among the mixes were compared at the densities produced by a 50-blow Marshall hammer or at an equal "compactive effort" not an equal "density."

To practically accomplish the above, the densities of the kneading compacted specimens were varied so as to "bracket" or "span" across the 50-blow Marshall density. A modulus vs. density is plotted on a graph and the Creep Stiffness Modulus for a particular mix determined at the 50-blow density point. A straight line or linear regression for each mix is shown in Figure 2.

The 50-blow Marshall densities and their associated Creep Stiffness moduli are listed (page 4) and shown in Figure 3. Again all of the mixes used 5.25% VAC-10.

Mix	Marshall Density (pcf)	Creep Stiffness Modulus (psi)
1. 50% Sand/50% Limestone	143.54	3,015
2. 25% Sand/75% Limestone	142.69	9,605
3. 100% Limestone	138.63	15,300

DISCUSSION

Clearly, the highest mix stiffness occurs with 100% crushed limestone. Going from 50% to 75%, and then to 100% crushed limestone rock substantially increases the stiffness for each step.

The Marshall data in Table 3 indicate a decrease in the 50-blow Marshall density as the percentage of crushed particles increase. This will normally result in a corresponding increase in the VMA, voids in the final mix, Marshall stability, and a decrease in the VFA as shown in Table 3. The Asphalt Institute (A.I.) recommends a minimum VMA of 15% for this particular aggregate gradation. The 100% crushed mix (using Procedure III density) is the only mix that meets this criteria. The A.I. also recommends a void content of 3-5% for surface courses, a minimum VFA of 70%, a flow of 8-16, and a minimum Marshall stability of 750 lbs. Therefore, examining Table 3 further, the 50/50 mix contains all the asphalt that it should, but more asphalt should be added to the 100% mix. The asphalt addition would increase the VFA and decrease the voids to within a more acceptable limit which would in turn increase the durability of the mix.

Table 2 (Gyratory Data) shows a decrease in the Gyratory Electro Plasticity Index (GEPI) with increasing amounts of crushed aggregate. No limits on the GEPI have been established as of yet, but it is a measure of the instability in only the aggregate combinations. An increase of the GEPI with more sand content, indicates an increase in rutting susceptibility before any asphalt is even added.

The Gyratory Stability Index (GSI) will indicate a stable or unstable bituminous mix (aggregate and asphalt) at 5.25% VAC-10 and at 45 revolutions. The 50/50 mix was the first to show bituminous mix instability which occurred at 6.25%. The other mixes would also become unstable but above the 6.25% asphalt content. This data seems to support the previous Marshall data in that certainly more asphalt could be added to the 100% mix without causing any appreciable decrease in the mix instability.

CONCLUSIONS

In my opinion, the following conclusions can be reached.

1. Increases in the crushed limestone aggregate above 50%, will result in increased creep modulus stiffness.

2. Comparing Creep Stiffness Modulus among different bituminous mixes should be done at the densities corresponding to the same compactive effort but not necessarily at equal densities.

3. At the same asphalt contents, increases in the crushed limestone aggregate will result in a lower Gyratory Electo-Plastic Index.

Table 1. Materials Used.

	Sieve Analysis % Retained									
	3/4	1/2	3/8	4	8	16	30	50	100	200
Target Gradation	0	5.0	12.0	25	47	69	82	91	94	95
1. 50% CS	0	11	24	50	67	67	81	87	89	90.7
50% SSG				0	26	74	83	95	99	99.9
Combined(Actual)	0	5.5	12.0	25.2	46.8	69.1	82.1	91	94.3	95.3
2. 75% CS	0	7	16	3.3	54	67	82	90	93	93.1
25% SSG				0	26	74	83	95	99	99.9
Combined(Actual)	0	5.0	12.0	25.3	46.9	68.0	82.7	90.6	93.6	94.8
3. 100% CS(Actual)	0	4.2	12.0	24.6	46.9	68.6	82.4	90.7	94.0	95.2

CS (Crushed Limestone)
Bates County Rock Co.
Linn County E½, Sec. 22, T 19 S, R 25 E.

SSG (Sand Gravel)
Victory Sand & Gravel Co.
Shawnee Co., Kansas River

VAC-10 (Derby Refining Co.)
87-477

Table 2. Gyratory Data.

% VAC-10	GEPI 50/50	GEPI 75/25	GEPI 100	GSI 50/50 (45 Revs)	GSI 75/25 (45 Revs)	GSI 100 (45 Revs)	DENSITY (pcf) 50/50 IV (45 Revs)	DENSITY (pcf) 75/25 IV (45 Revs)	DENSITY (pcf) 100/0 I / IV (45 Revs)
3.75	1.73	1.63	1.48	1.00	1.00	1.00	142.97	141.29	140.67/135.97
4.25	1.73	1.61	1.51	1.00	1.00	1.00	144.46	141.98	141.66/138.04
4.75	1.83	1.79	1.60	1.00	1.00	1.00	145.08	-	143.09/139.01
5.25	1.83	1.73	1.58	1.00	1.00	1.00	145.66	143.91	142.73/138.71
5.75	1.81	1.73	1.59	1.00	1.00	1.00	146.71	144.76	144.26/141.05
6.25	1.83	1.75	1.60	1.12	1.00	1.00	148.01	146.61*	144.52/141.51

*based on 50 revolutions.

Table 3. Marshall Data/5.25% VAC-10.

Mix		50/50			75/25			100/0		
Density Proced. KT-15		I	III	IV	I	III	IV	I	III	IV
Density	(pcf)	147.45	146.76	143.52	145.95	145.51	142.71	142.46	141.46	138.65
Abs. Asphalt	(%)		1.0622			1.0722			1.2942	
VMA	(%)	12.33	12.74	14.67	13.36	13.62	15.29	15.04	15.63	17.31
VFA	(%)	75.03	72.29	61.40	68.40	66.90	58.46	56.17	53.65	47.50
Voids	(%)	3.08	3.53	5.67	4.22	4.51	6.35	6.59	7.25	9.09
Stability	(lb)		1117			1814			2333	
Flow	(.01 in.)		8			13.8			10.8	
Bearing Capacity			156			140			236	
Air Perm. ($X10^{-10}cm^2$)			89 very low			56 very low			178 very low	

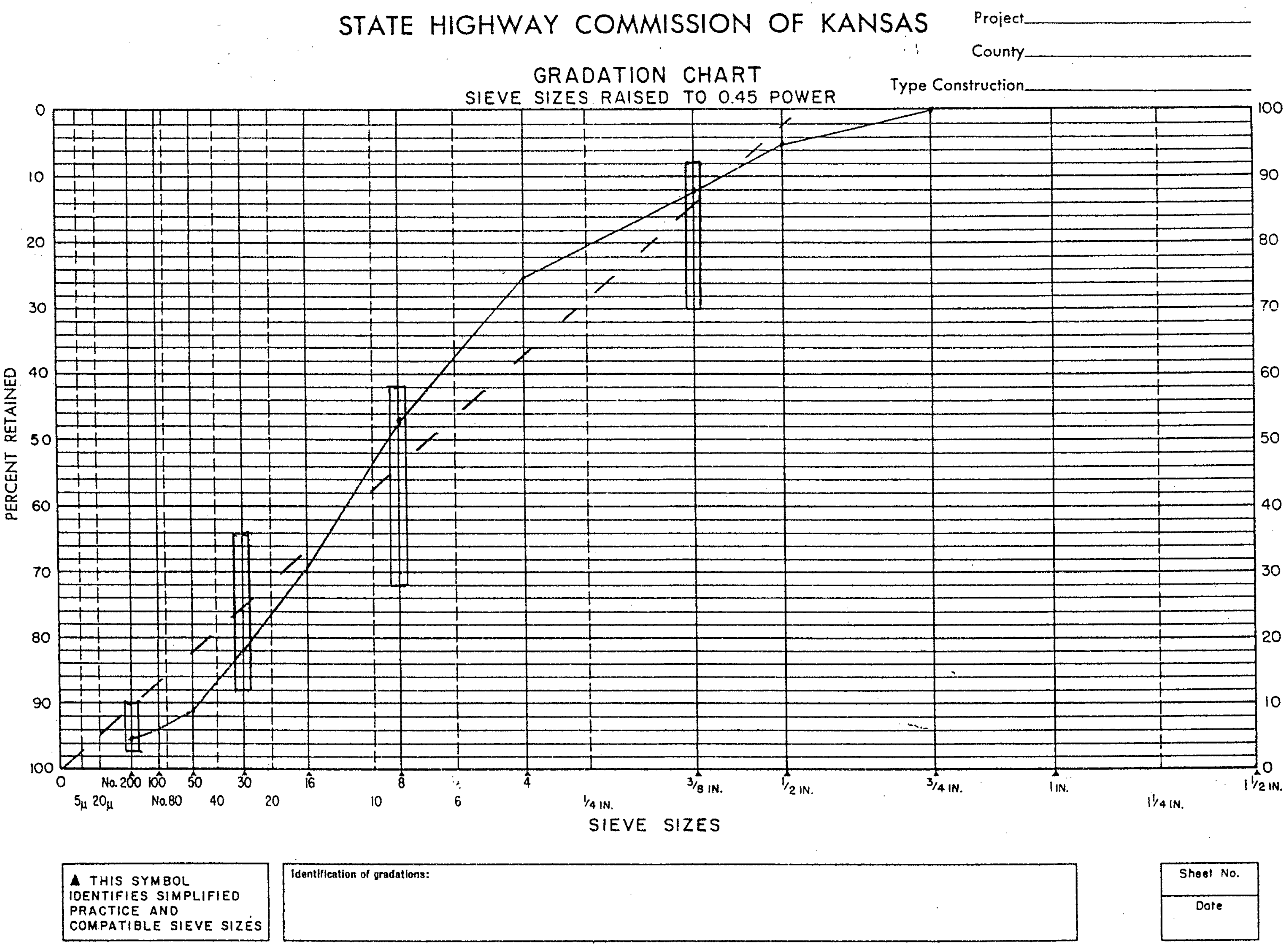


FIGURE 1. Typical BM-2 Gradation.

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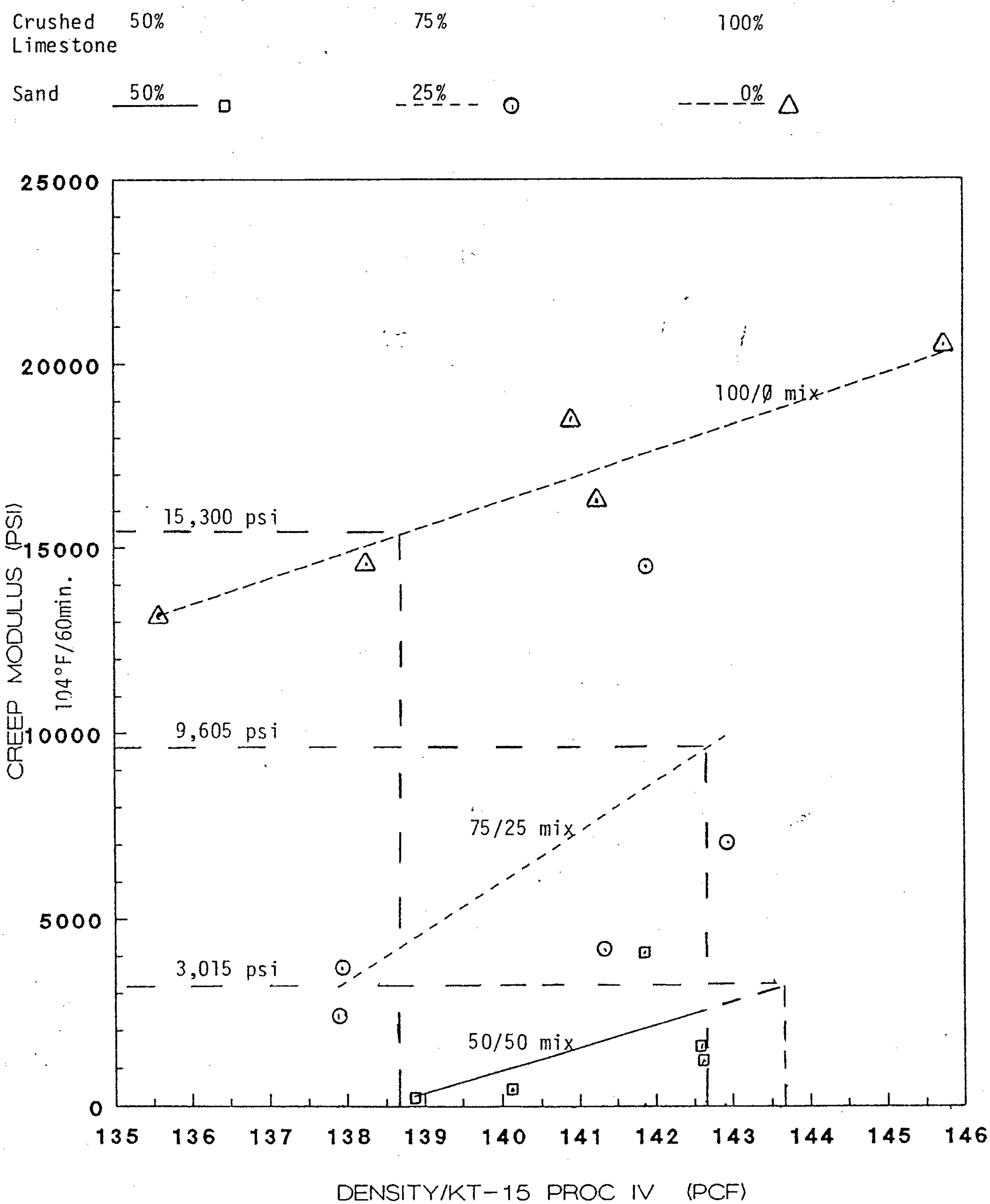

FIGURE 2. Creep Modulus vs. Density.

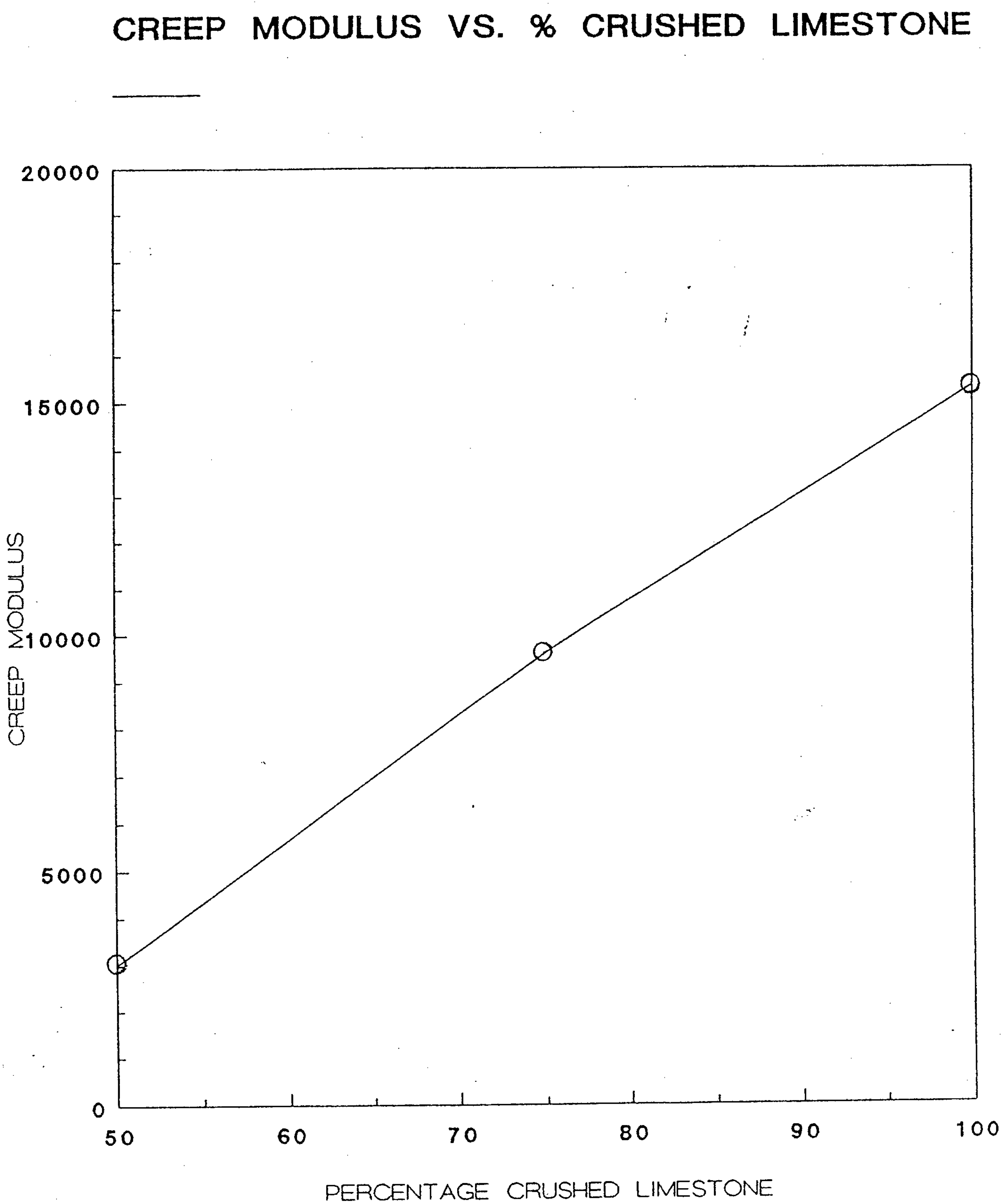

FIGURE 3. Creep Modulus vs. Percentage Crushed Limestone.

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